ASTRALite's prototype bathymetric LiDAR set up to scan from a bridge.
Provided by ASTRALite

LITTLE TOPO-BATHY LIDAR

Topographic—Bathymetric (Topo-Bathy) LiDAR has been a very important part of the remote sensing and mapping profession for some time now. Most of the major LiDAR sensor manufactures have a Topo-bathy sensor offering. These sensors operate at a wavelength of 532 nanometers (nm) using Nd:YAG lasers. The traditional topographic LiDAR's operate between 905 and 1550 nm employing near-IR lasers. LiDAR sensors that operate at 532 nm can also be referred to as bathymetric LiDAR. These sensors can also collect topographic information at this wavelength so that is where the Topo-bathy comes from. It should also be noted that depending on the topo-bathy supplier the data can include results from both 532nm and 1064 signals. There really isn't a specific way this data has to be developed and just because one supplier does something different from another doesn't mean the solution is less valid. At the time of the introduction of Bathymetric LiDAR, these sensors where very expensive and now they are considerably less expensive but the cost to collect bathymetric LiDAR can still be relatively higher than other methods of LiDAR collection. There are several reasons for this as providers have to amortize the cost of the system and the processing is more labor intensive then other forms of LiDAR. An example of additional processing is correcting for the refraction of the pulse as it passes from the air into the water column and then hits the surface under the water.

> "Just because one supplier does something different from another doesn't mean the solution is less valid."

BY JAMES (JAMIE) WILDER **YOUNG**

Representation of Optech Titan captured Topo-bathy LiDAR using the 532nm,1064nm,1550nm sensors in addition to Titan Captured Imagery.
Provided by Jamie Young.

The benefits provided from bathymetric or Topo-bathy LiDAR are significant. Recently, a company called ASTRALiTe based in Boulder, Colorado has developed a very compact light weight bathymetric LiDAR. This Bathymetric LiDAR is the size of a text book.

The ASTRALiTe bathymetric LiDAR has much potential as it relates to the current state of the profession. ASTRALiTe is currently operating this sensor on tripods mapping water surface, underwater structure and water floor surface for many applications. They are in the process of developing a version of the sensor that will be mounted on a drone. In the past, small-scale bathymetric projects would be cost prohibitive based on the amortization cost of the larger fixed wing or helicopter bathymetric or topo-bathy solutions. The ASTRALiTe solution will provide a much more affordable option. Obviously, this additional bathymetric solution will be a welcomed additional tool to the geo-nerd toolbox . It will not replace the current bathymetric or topo-bathy solutions but will complement them.

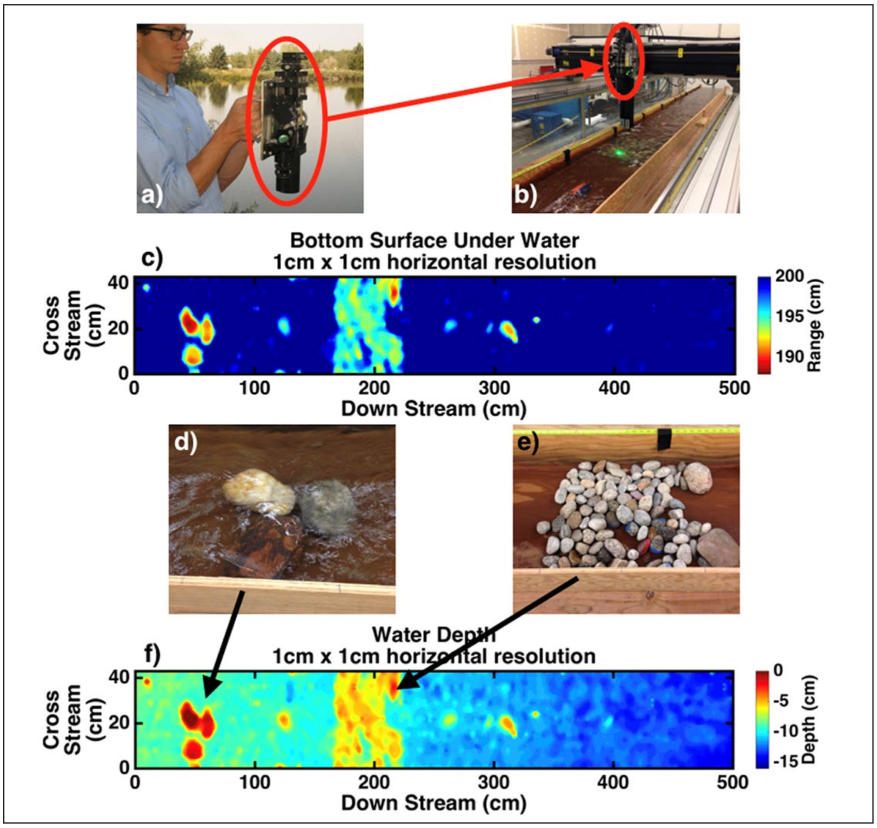
The current bathymetric LiDAR sensors operate at a varying array of repetition rates and, depending on the sensor manufacturer, the repetition rates are very specific as it relates to the specific intended functionality of the system. The Optech Titan which is a Topo-bathy LiDAR which operates from 532nm to 1550nm can operate at a Ground sampling rate of up to 300kHz for its bathymetric sensor. The Optech CZMIL Nova sensor operates at up to 70Khz. Riegl offers the VQ-880-G and VQ-820-G Topo-bathy LiDAR sensors which operate at up to 550Khz and 520kHz respectively. Hexagon offers the HawkEye III Deep Bathymetric LiDAR and Chiroptera II topo-bathy LiDAR sensors. The Chiroptera II operates at 35kHz and the Hawkeye III has two channel at 35kHz and 10kHz. Most of the systems above all have a higher repetition rate for their Topo LiDAR function. The depth at which all of these sensors can map under the water depends on water characteristics such as water clarity, as well as the lidar design

	Prototype Specification	Anticipated UAV Product Specification
Power Consumption	200w	50w
Min Range through air	1m	1m
Max Range through air	10m	30m
Max Depth	1 Secchi Depth	1.3 Secchi Depth
Range resolution	< 1 cm	< 1 cm
Water Depth resolution	< 1 cm	< 1 cm
Laser Rep Rate	8kHz	20kHz
Laser wavelength	532 nm	532 nm
Laser Footprint	5cm at 5m	5cm at 20 m
Dimensions (L x W x H)	30 x 30 x 30 cm	30 x 15 x 15 cm
Weight	10kg	4 kg
Data Rate	300kB/s	500 kB/s
Data latency	0.1 s (realtime)	0.1 s (realtime)
Additional Sensors	IMU	Can incorporate scan system, IMU, Camera, etc.
System Design	handheld Unit	UAV, Airplane, Handheld, Boat mounted
Measurement Type	Time of Flight	Time of Flight

Table 1: Prototype and Anticipated Project Specifications

characteristics such as laser power, size of telescope, sensitivity of detectors, etc. It is very important to contact the appropriate sensor manufacture to understand exactly what each sensor does best, but roughly speaking these systems can measure from a few meters into the water up to 80 meters in clear water conditions. Typically, the lower the average power (or, for fixed pulse energies, the lower the repetition frequency) the less depth lidar systems can measure into the water. Furthermore, the longer the pulse width the lesser ability these systems have in resolving shallow waters (< 2m) but again please contact all the manufactures for the most accurate information.

ASTRALiTe is a Subsidiary of ASTRA, LLC (http://www.astralite.net/) . It currently operates at 8KHz but they have plans to release a drone version that can operate at 20kHz. Given that this sensor will be used on a drone and the flight altitude for the drone is much lower than other Bathymetric LiDARs, it can be deduced that a much higher rep rate is not necessary. The current ASTRALiTe range resolution is 1cm with an underwater terrain resolution of 1cm. The current ASTRALiTe sensor provides real time results from the sensor. **Table 1** represents the current configuration of the ASTRALiTe prototype and the anticipated product specification.

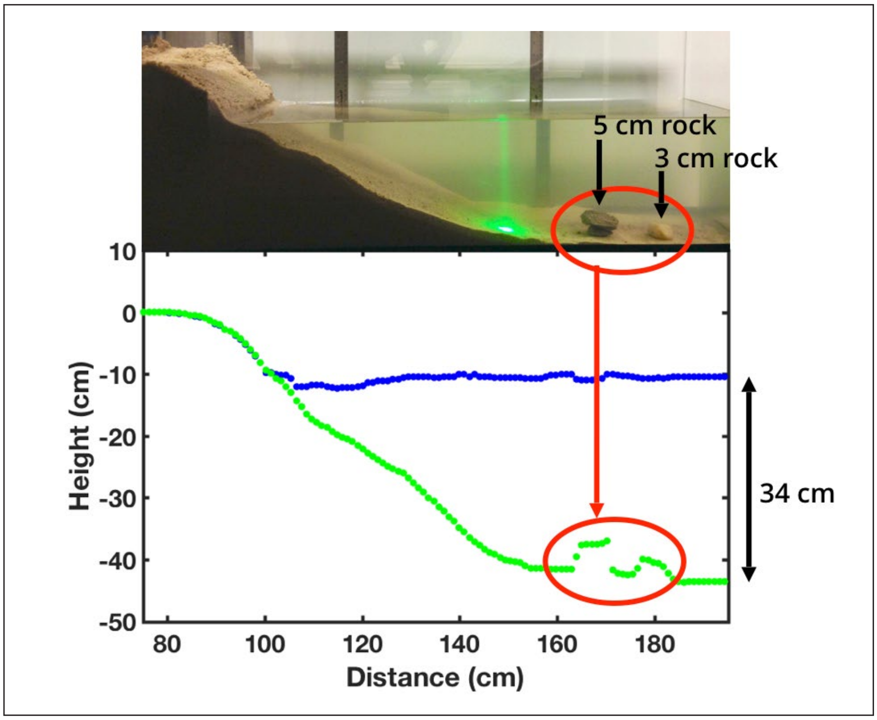


ASTRALite set up for the USGS shallow water test figure a) and b), Bottom surface under water of the test channel figure C), test rock locations figure d) and e) as they relate to the water depth information in figure f).

Provided by ASTRALite

A major limitation to conventional LiDAR bathymetric measurements is their inability to operate effectively in the shallow water domain [Guenther and Maune, 2007; Allouis et al., 2010; Pe'eri et al., 2011]. This limitation is caused by the lack of range resolution in these LiDAR measurements, typically 50-100 cm or worse. This lack of range resolution is due to the fundamental fact that to unambiguously delineate between the water surface and a submerged object requires the ability to discern disparately different levels of backscattered signals in very short time intervals. Although such capabilities have been implemented in modern-day LiDAR bathymetric systems [e.g., Feygels et al., 2013; Nayegandhi et al., 2009], they are generally expensive, complex, heavy, require technical operators, and employ extensive signal post-processing (i.e. no real-time information).

A breakthrough in achieving high-resolution range measurements of submerged objects in shallow water with less complexity was made by Professor Jeff Thayer's LiDAR research group at University of Colorado at Boulder (CU) by exploiting the polarization of light and its discriminant interaction with the air-water interface and the water-bottom, or object, interface, while using modest laser systems and standard detectors [*Mitchell et al.*, 2010; *Mitchell and Thayer*, 2014]. Precise ranging of the two surfaces is achieved by isolating differently polarized returns and tagging their time of arrival. This description is embodied in CU's INtrapulse PHAse Modification Induced by Scattering (INPHAMIS) technique to achieve high resolution ranging in shallow waters [Thayer et al., 2016]. The invention is patented in both the US and Europe.



Top: ASTRALiTe LIDAR operating in USGS test pool
Bottom: represented profile of that location during the test.
Provided by ASTRALiTe.

Several polarization bathymetric LiDARs have demonstrated their applicability in deeper waters and have shown bottom return signals and interesting behavior between the co-polarized and cross-polarized signals [e.g., *Vasilkov et al.*, 2001; *Churnside*, 2008]. Using the polarization technique, ASTRALite has been able to resolve time differences at 27 picoseconds (10^{-12} seconds), or about 4 mm range resolution in water, for depths of several meters. This elegant solution to high-resolution range measurements in shallow water enables the development of a less expensive, simplified LiDAR system, while at the same time providing a 50- to 100-fold improvement in underwater range resolution versus other bathymetric LiDAR systems.

In laboratory-scale tests ASTRALiTE has demonstrated precise ranging to submerged objects using the INPHAMIS technique. As a demonstration of this novel capability to accurately range to the surface and bottom, determine water depth, and map subsurface features under running water, ASTRALite demonstrated their LiDAR unit at the US Geological Survey (USGS) geomorphology and sediment transport laboratory. The LiDAR demonstrator unit was mounted on a linear x-y scan system over a flowing river scene in the USGS facility. The entire river scene encompasses a horizontal size of 45 cm x 500 cm. Rocks were placed into the riverbed to provide submerged objects to detect and flowing water was circulated through the flume to create a rough water surface.

The ASTRALiTe LiDAR unit scanned with 1 cm x 1 cm horizontal resolution and yielded < 1 cm vertical resolution, thus providing an unprecedented detailed estimate of both subsurface topography and water depth. For this demonstration, the measurements were performed under very shallow waters ranging from about 9 to 13-cm of water depth. ASTRALiTe and the author are not aware of any other measurement technique that can work in this situation for measuring such extreme shallow water depths under flowing water conditions. The depth measurements were verified with ruler measurements at a few points along the river, which demonstrated sub-centimeter accuracy. Features such as individual rocks are immediately obvious in the data.

Commonly only 10-50 pulses are needed to estimate range with centimeter precision. With high laser repetition rates, each position can be recorded in milliseconds. ASTRALite detection scheme also produces low data rates as only the precise time of a detection is recorded so that the area being scanned can be visualized in real time.

The testing at the USGS facility demonstrated that the LiDAR technique works well in a variety of shallow-water conditions in a controlled laboratory. Outside of the lab setting, ASTRALiTe is addressing additional challenges that are introduced by the surface sea state, water turbidity, suspended materials, bubbles, phytoplankton, dissolved materials, and scattered sunlight.

The high-resolution ranging to submerged objects is an important achievement opening new opportunities for bathymetric LiDAR to contribute to shallow water measurements. In particular, this new high resolution capability means that the INPHAMIS lidar can be used where the other existing lidars do not perform well—from the shoreline out to depths of a few meters. Furthermore, ASTRALiTE's approach overcomes the signal contamination from surface scatter that plagues other bathymetric LiDAR systems, and thus enables range measurements and target identification at high resolution by INPHAMIS over a broad range of distances from the water. This means the INPHAMIS system can be operated from a boat, a UAV or an airplane with similar success. Other LiDAR systems overcome these signal contamination issues by gating the receiver and limiting the measurement to specific range-observing windows, but this results in poor vertical resolution and a limited coverage in possible range locations.

ASTRALite's new very small bathymetric LiDAR sensor provides a unique solution, with significant advantages relative to other Bathymetric and topo-bathy LiDAR sensors. To summarize the advantages are: high resolution of less than 1 cm, real-time processing and visualization, low Swap (size, weight and power) and low costs. The design is scalable for different water conditions. The future adoption of this technology by itself and potentially in combination with other sensors provides a very cost effective solution for smaller projects when traditional bathymetric might be cost prohibitive. The high resolution and realtime analysis also opens up new markets for the inspection of underwater infrastructure, for example. This is a welcomed technology to add to the geo-nerd tool box.

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